REPLICA GRATING STUDY
NGR-22-091-002

INTERIM REPORT

December 1, 1966 - July 1, 1967

College of the Holy Cross
Worcester, Massachusetts

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Abstract

The thermal-vacuum testing of samples of 1 meter concave replica diffraction gratings has been started. The first test, subjection of the gratings to pressures in the 10^{-9} torr range and at ambient temperature, has been completed. The gratings showed no significant change in line profile. Two plane gratings were subjected to pressures in the 10^{-13} torr range at ambient temperature and showed no significant change in their interferograms.

Irradiation of a series of plane replica diffraction gratings 50 mm diam. by 10 mm thick and aluminized substrates of identical material (pyrex) and dimensions showed distortions of the interferograms starting at about 10^{12} electrons/cm^2. The distortion appeared to be the same in both replica gratings and aluminized substrate material leading to the tentative conclusion that at this energy level it is probable the substrate material rather than the replication process that would be the source of trouble.

1. Purpose of Effort

Phase I of this study established the broad basic direction the project was to take. In Phase II the directions indicated in Phase I were pursued. Specifically the purpose of Phase II are:

1.1 Extension of the thermal-vacuum tests to include concave replica gratings in the HCO tank (10^{-9} - 10^{-10} torr range) and plane replica gratings in a tank at NASA GSFC (10^{-12} - 10^{-13} range).

1.2 Extension of the 1.2 Mev electron radiation study to include:

1.2.1 Literature search of variation of dose with orbits in which grating experiments might be involved.

1.2.2 Determination with plane gratings of point at which distortion begins to appear.

1.3 Extension of interferometric studies from plane gratings only to concave gratings.

2. Nature of Effort

2.1 Thermal-Vacuum Tests

2.1.1 10^{-9} torr range

At this time a Bausch and Lomb, a Diffraction Products, and a Jarrell-Ash concave replica grating have been subjected to the first in a series of thermal-vacuum tests in the 10^{-9} torr range. This first test was at ambient temperature and the pressure maintained at less than 2 x 10^{-9} torr for 4 days. Inspection of the line profiles of various lines in the He and Hg spectra from 584A to 5461A shows no significant variation pre and post stress. The gratings have now been returned to the Harvard College Observatory (HCO), Solar Satellite Project, for stress in this same pressure range but at reduced temperature.

2.1.2 10^{-13} torr range

Three 2¼" x 2¼" x 3/8" plane Jarell-Ash replica gratings with pyrex substrates were exposed to pressures in the 10^{-13} torr range and at temperatures and durations as shown in Table I. The work was done for us at GSFC under the supervision of Mr. Charles E. McAndrew.

TABLE I

Ultra-Low Pressure Thermal-Vacuum Stress of Plane Replica Gratings

	Duration of Exposure (Hours)	Duration of Pressure (x 10^{-13} torr)	Duration of Temperature (°C)
Grating #1	50	1.1 ± (.2)	29.0 ± (.5)
Grating #2	50	1.1 ± (.2)	11.8 ± (.5)
Grating #3 (Control)	50	1.1 ± (.2)	23.8 ± (.3)

Grating #3 was a control with a thermocouple not only on three sides but also in the middle of the ruled surface.

Interferometric examination in a Twyman-Green type instrument showed no significant distortion produced by this stress.

2.2 Particle Irradiation Studies

2.2.1 Literature Search of Variation of Dose with Orbits in which Grating Experiments Might be Involved.

A study was made at GSFC, following a suggestion by Dr. F.W. Paul and under the subsequent supervision of Mr. Charles E. McAndrew and Dr. E.G. Stassinopoulos, as to whether the current one year equivalent dose of 1.2 Mev electrons in the Van Allenbelt was typical of exposures actually experienced by unshielded gratings. This study, reported previously, showed year doses for 1.2 Mev electrons as low as 1×10^6 electrons/cm^2/year for a 0^o inclination, 300 n mi radius up to 4×10^{11} electrons/cm^2/year for a 90^o inclination 450 n mi radius. These doses are those projected for 1968.

Actual data is sparse but what is available has shown a range from 4×10^9 electrons/cm^2/year to 5×10^{12} electrons/cm^2/year. The difference between the data projected for 1968 and the actual data is due in part to the variability of the radiation in space.

A further computer study was made by Dr. Stassinopoulos and was reported in a memorandum to Mr. McAndrew dated April 12, 1967. Subject to the qualifications appended to the memorandum it would appear that the orbit integrated omni-directional vehicle encountered 1-2 Mev electron flux as of May 15, 1966 was about 7×10^{11} electrons/cm^2/year. This is sensibly in agreement with the literature search earlier referenced.

2.2.2 Determination of the Dose at Which Distortion Begins to Appear in Plane Replica Diffraction Gratings.

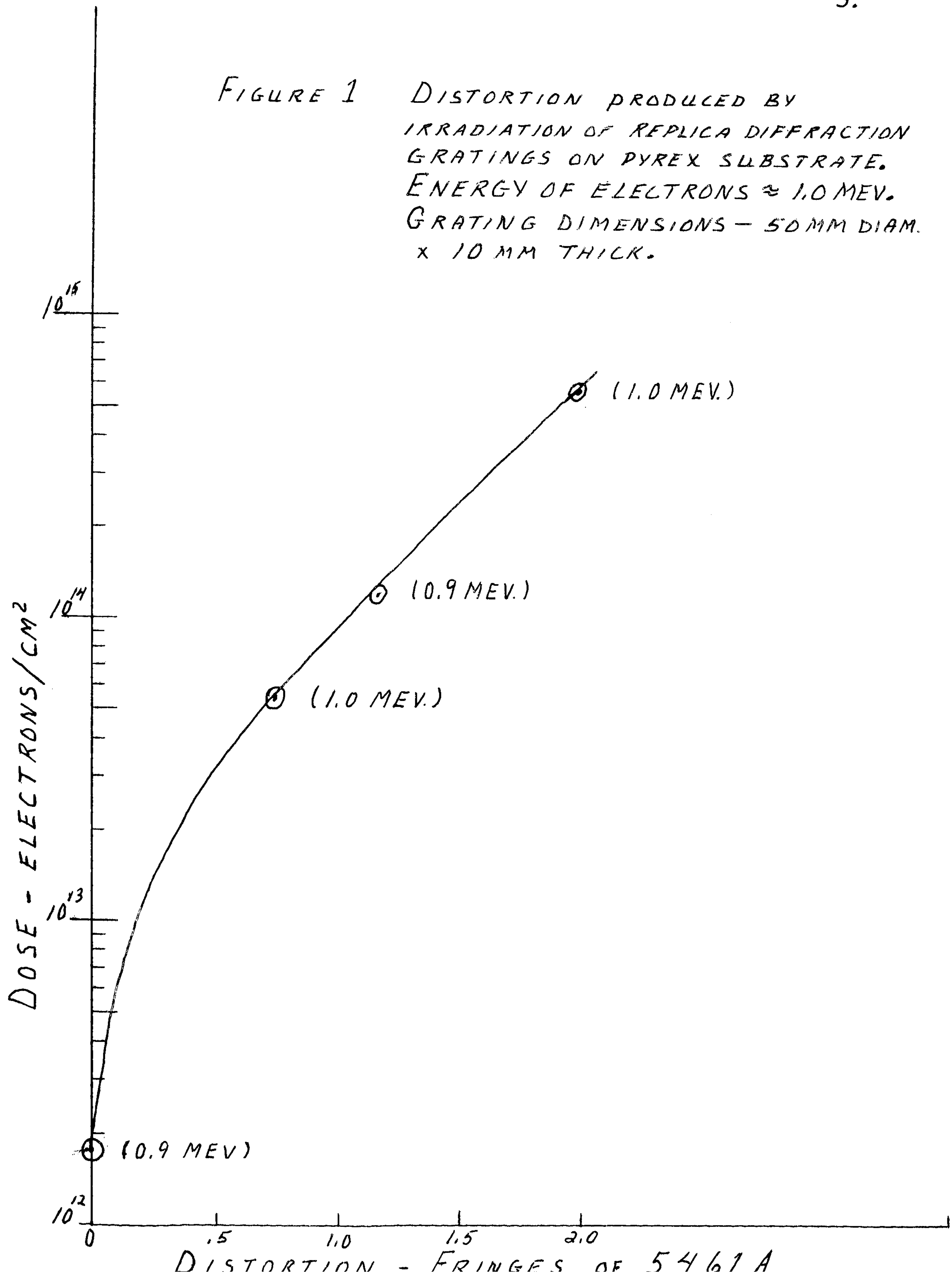
With the information from the studies in 2.2.1 at hand an experiment was initiated with the cooperation of the AFCRL Radiation Physics Branch to determine at what dose 1.2 Mev electrons would produce distortion in some special plane replica diffraction gratings. These gratings were on a pyrex substrate 50 mm diameter by 10 mm thick, with both front and back surfaces finished to about one-quarter wavelength of 5461A radiation. Not only were the replica gratings irradiated but also irradiated were aluminized substrates of exactly the same dimensions and material. This experiment was similar to that done earlier but this time under much closer control. The energy was maintained at 1.2 Mev in the Dynamitron drift tube. The calculated energies at the target are shown in parentheses at each of the data points. The gratings were examined pre and post irradiation and the variation in distortion as measured on a Twyman-Green instrument as a function of dose is shown in Figure 1.

Several rather interesting results were gleaned from this experiment.

2.2.2.1 The variation of distortion was approximately linear above 10^{14} electrons/cm^2.

2.2.2.2 The variation of distortion was approximately 0 at 10^{12} electrons/cm^2.

FIGURE 1 DISTORTION PRODUCED BY IRRADIATION OF REPLICA DIFFRACTION GRATINGS ON PYREX SUBSTRATE. ENERGY OF ELECTRONS ≈ 1.0 MEV. GRATING DIMENSIONS — 50 MM DIAM. x 10 MM THICK.



2.2.2.3 The front surface, i.e. the surface facing the oncoming radiation, went convex.

2.2.2.4 The rear surface went concave the same amount as the front surface went convex - at least to within a fraction of a fringe.

2.2.2.5 Of great importance was the observed fact that, at least for these particular gratings, the variation in distortion in the grating was the same as that of the aluminized substrate alone.

2.2.3 Extension of Interferometric Studies from Plane Gratings Only to Concave Gratings.

Numerous workers have indicated the desirability of having an interferometric as well as a spectrographic analysis of gratings. A fairly straightforward method was developed by G.W. Stroke (J.O.S.A. 45, 30 (1955)) for plane gratings and has been used extensively since that time. A comparable approach has been used for concave using a Twyman-Green interferometer but interpretation of the significance of the fringes in the presence of the aberrations of the surface was difficult. We have been studying this problem for sometime and have looked at both the Ronchi and Zone Plate Interferometer approaches. Most recently we have been studying a method proposed by K.G. Birch (J.Sci. Instr. 43, 243 (1966)) for the interferometric examination of the ruling errors of a concave grating. This method uses a single parallel plate to effect a shearing of the beam from the grating with itself. The method as applied to concave mirrors was discussed previously by M.V.R.K. Murty (Applied Optics 3, No. 4, 531 (1964)) and in both instances a He-Ne gas laser is used.

Tests to date have indicated definite promise of this method. The first work was done with a relatively crude set-up and the initial success has led us to refine the method. Interferograms were obtained with the early set-up and are expected from the new and improved method shortly.

3. Conclusions

3.1 Thermal-Vacuum Stress

On the basis of as yet incomplete thermal-vacuum tests it would appear that the line profiles from the three commercial 1 meter concave gratings tested have not shown any degradation when subjected to a vacuum of 10^{-9} torr for several days at ambient temperature. One set of plane gratings also showed no interferometric distortion when subjected to a pressure of 10^{-13} torr for several days at ambient temperature.

3.2 1.0 Mev Electron Irradiation Stress

Irradiation of a set of replica diffraction gratings and aluminized substrate material of the same material, pyrex, showed distortions starting at slightly in excess of 10^{12} electrons/cm^2. The distortion was convex towards the beam and was the same for both replica gratings and aluminized substrates. The rear surface went concave the same amount as the front surface went convex.

3.3 Interferometric Analysis of Concave Gratings

The shearing method of Birch appears to have significant promise.

4. Plans for Forthcoming Six-Month Period

4.1 Thermal-Vacuum Tests

The three concave replica gratings will be tested in the HCO tank at reduced and then elevated temperatures. Currently we are hoping that the very high vacuum tests being conducted at NASA-GSFC will be continued so we can also complete this series. The in-situ tests are still in the preliminary stage and this work will be continued. If funds allow, we plan to purchase a thermal system that will allow us to control the temperature of the gratings while they are under test.

4.2 Particle Radiation

4.2.1 1.2 Mev Electrons

After the thermal-vacuum tests are completed in the HCO chamber, the three commercial type concave gratings will be subjected to increasing doses of radiation starting at 10^{11} electrons/cm^2 and continuing until a significant degradation in performance occurs. Figure I of this report indicated that distortion started to occur in the interferograms of some plane gratings at 10^{12} but we will start a decade lower to insure that we are at the zero distortion point. These concave gratings will be examined in our monochromator primarily for variation in line shape. It is hoped that by the time we are ready to irradiate, we will also be able to examine the gratings interferometrically using Birch's method or a modification thereof.

4.2.2 Positive Particles

Currently under installation at Holy Cross is a 2 Mev Van de Graaff Generator. It is anticipated that some positive particle irradiation will start - probably initially on plane gratings - during the forthcoming period.

4.2.3 Electrons of Other Than 1.2 Mev Energy

We plan as soon as possible to examine the effects of negative particle irradiation that would be captured entirely in the "plastic layer" of the replica grating. Electrons of energies less than 1.2 Mev abound in space and the experiments reported in Figure I plus the suggestions of F.W. Paul regarding precisely this same point indicate we must look at this matter carefully.

4.3 Efficiency Measurements

With the approval of our supplementary funding request we are initiating a new phase of effort - one in which we will not only be able to measure line profile but also relative efficiency. The instrument should be delivered according to present plans within six months.

5. Personnel

5.1 Senior Staff

While each of the senior staff participated in some phase of all of the tests, the principal area of responsibility of each investigator is as shown.

Dr. Roy C. Gunter, Jr., Holy Cross College--principal investigator

Dr. Edward F. Kennedy, Holy Cross College--irradiation

Dr. Francis W. Kaseta, Holy Cross College--electrical measurements

Mr. Robert F. Kelley, State College at Worcester--in-situ thermal stressing

Mr. George E. Schmidt, Jr., Worcester Polytechnic Institute--electron micrographs

5.2 Student Staff

Although many students have been involved in one phase or another of the program, the following were those with specific assignments:

John Ebersole--optical tests

Robert Gibbons--vacuum equipment/tests

William Mueller--line profiles

Mark Roberts--line profiles

5.3 Support from Other Laboratories

Mr. Lester F. Lowe, AFCRL - irradiation tests

Dr. Mason C. Cox, Dr. Paul M. Waters, Dr. Richard F. Woodcock, Mr. Samuel F. Walton, Mr. Colin Yates Research Department of America Optical Co. -- glass stressing and tests

Dr. E.M. Reeves, Mr. Nathan Hazen, Mr. Frank Kaszinski, Mr. James MacDonald, Harvard College Observatory - thermal-vacuum tests

Mr. Richard Schmitt and colleagues of the Jarrell-Ash Co. Grating Laboratories

Dr. Irwin Loewen and colleagues of the Bausch and Lomb Co. Grating Laboratory